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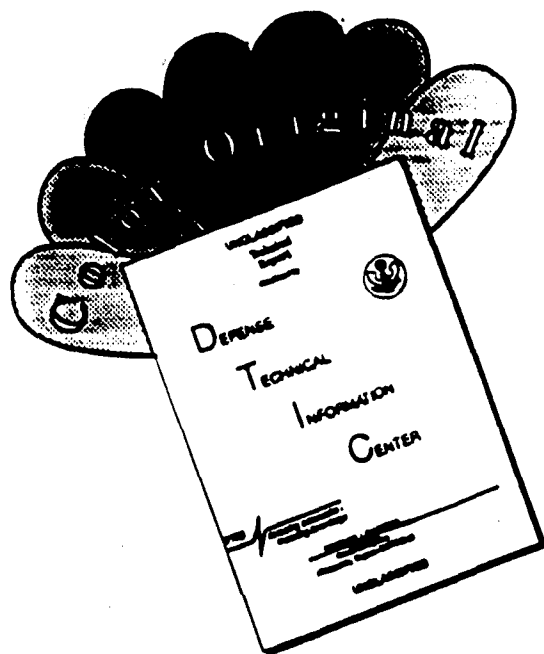
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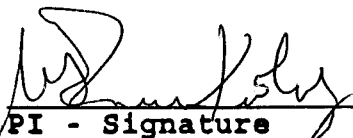
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**“Real-Time, Light Weight, X-ray Imager”
Sensor Plus, Inc.
Final Report**

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"Real-Time, Light Weight, X-ray Imager"

Sensor Plus, Inc.

Final Report

1 Introduction

Radiographic film is the most common conventional detector in which scintillation screen, together with a photographic film, is used. The scintillation screen is used to convert x-ray photons to visible light photons. The film is exposed during the radiation by the illumination of the fluorescent screen. Then it is chemically processed to obtain the resulting radiographic image. In this study, cost effective radiographic image reception device has been developed and fabricated to overcome the limitations of radiographic film and its processing. The new imaging device is intended to be used where film processing equipment or facilities can not be placed, and where on-line verification of the results is needed during the treatment; such as field hospitals or mobile medical units.

Pre-production prototype of a low-cost, compact digital radiographic imaging device which replaces current film based systems has been constructed and tested. Currently, it is in the process of full utilization for field hospitals where immediate verification of the results is essential. For the particular pre-production unit, image acquisition is performed by a 3x4 matrix of charge-coupled-device (CCD) imaging sensors which view the output of a standard x-ray scintillation screen via an off-the-shelf optical system (Fig. 1). The use of multiple, moderately priced CCD sensors results in a high resolution system with a low cost of production relative to other digital imaging systems of comparable resolution. The field of view of each CCD are purposefully overlapped so as to facilitate image reconstruction. The acquisition of each radiographic image formed on a scintillation screen results in the production of twelve sub-images. A software algorithm is employed to detect the regions of overlap and create a single, continuous digital radiograph from the raw CCD data.

The software interface controls the imager hardware, and performs image reconstruction and visualization tasks required by the system. Image reconstruction software consists of an algorithm to correct for barrel distortion affects that are caused by the use of low cost lens components, and sub-image alignment algorithm to create single, continuous radiographic image. The distortion correction and image alignment algorithms are discussed in detail. The image capture time is approximately 100 milliseconds. Retrieval and reconstruction of the complete image is performed in approximately 15 seconds. For the pre-production unit, screen to imager distance has been reduced down to 3 inches which further decreases the total imaging device thickness to 6 inches (Overall imager dimensions are now 8.5"Wx10.5"Lx6"H for 8"x10" view.). The radiographic images captured have 4 lines/mm resolution over the 8"x10" field of view.

The digital radiographic imager is of particular value in areas of medical radiographic imaging where on-line verification of the results are required. Furthermore, the compact system will allow the operator to use the imager in field hospitals or mobile medical units. Also, modularity of the CCD matrix layout allows the system to be reconfigured for different size imaging areas without any reduction of the spatial resolution per unit.

2 Requirements

Digital x-ray techniques present several advantages over conventional film based methods. Digital imaging allows the operator to view immediately the results of each radiograph, eliminating the traditional delay associated with film development and processing. Digital images may be further manipulated by physicians to enhance, magnify, and otherwise postprocess regions of interest. A low cost, compact digital x-ray imaging device which replaces current film based systems has been developed. The system is intended to be used in field hospitals where on-line verification is required during treatment.

The development goals for the compact x-ray imager system were as follows;

- * Acquire a digitized image for further image manipulation and processing,
- * Present the images immediately to the operator during treatment,
- * Maintain compatibility with conventional radiographic film sizes,
- * High degree of system portability for use in field hospitals,
- * Dynamic range and spatial resolution comparable to conventional systems,
- * Relative low cost,
- * Open / Expandable system architecture (change of detector area).

The x-ray imager is expected to be of utility to multiple branches of radiology, particularly in field applications requiring a compact unit with on-line verification.

3 Architecture

Image acquisition is performed by a 3x4 matrix of charge-coupled-device (CCD) imaging sensors which view the output of a standard x-ray scintillation screen via an off-the-shelf optical system. The use of multiple, moderately priced CCD units results in a high resolution system with a low cost of production relative to other digital imaging systems of comparable resolution. The acquisition of each radiographic image formed on a scintillation screen results in the production of twelve sub-images. A software algorithm is employed to detect the regions of overlap and create a single, continuous digital radiograph from the raw CCD data. Software methods are utilized to correct for barrel distortion affects that are caused by the low cost lens components.

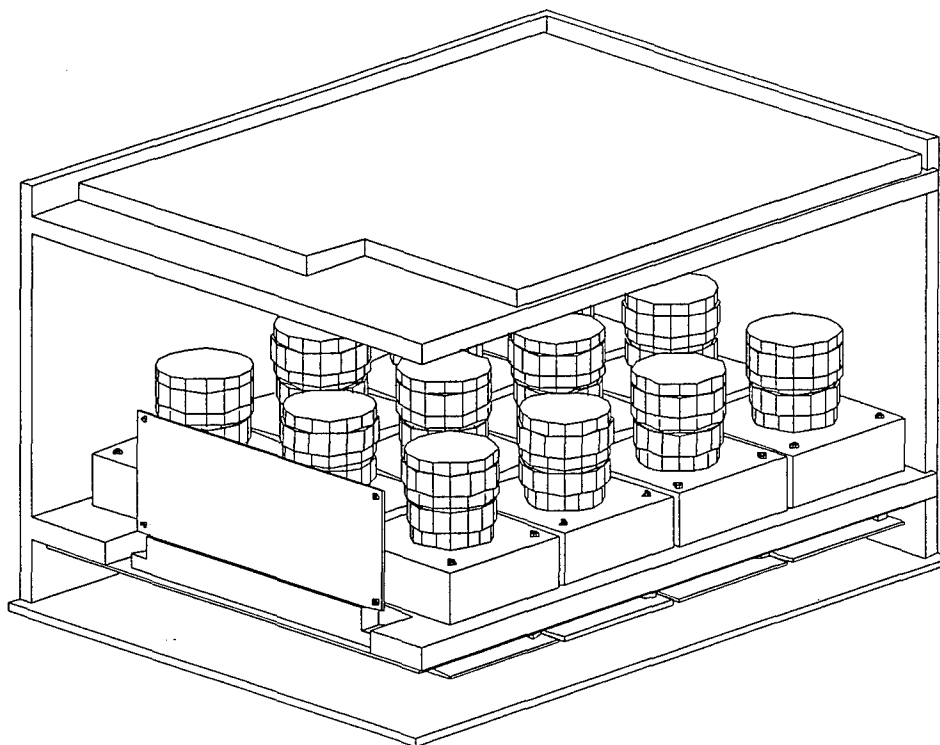


Fig. 1 Imaging Device (Open View).

The system has been designed to include the following sections; A fluorescent screen to convert x-rays to visible light, Multiple image-sensor/lens pairs each capturing one segment of the image on the fluorescent/optical screen, Data acquisition system to condition CCD's analog signal output and to obtain digital pixel information, Memory/interface unit to store the acquired data and to transfer the data to a computer system for further processing, Portable computer system with display, Touch screen for system/operator interaction, Alignment grid for the calibration of the detector, Reconstruction software for the alignment of the individual segments, and Image processing software for further refinement of the images by an operator.

High internal image resolution is achieved with moderate quality system components and moderate resolution CCDs by combining subsection images. Radiographic images on the order of 3 lines/mm (or 768x1000 pixels) are acquired rapidly over a 8"x10" field of view. A matrix configuration of twelve CCD area imagers are utilized in parallel so as to reduce significantly screen to imager distance and acquisition time. Modularity of the CCD matrix layout allows the system to be reconfigured for different imaging areas without any reduction of the spatial resolution per unit. Successful operation has been verified using a screen to imager distance of 4 inches with off-the-shelf optics. Further distance reductions are possible with custom optical configurations. The captured radiographic images are displayed instantly on an CRT and/or LCD depend upon the computer system configuration.

Fluorescent Screen:

The device uses a commercially available Kodak Lanex intensifying screen. The spectral response of the Lanex screen begins at 415 *nm* and extends through 630 *nm*, with a peak response of energy located at 545 *nm* accommodating with the spectral response of the imaging sensor which is 400 *nm* to 600 *nm* with the peak at 550 *nm*. The specified resolution of the screen is 100 microns. Light output conversion efficiency for a 50 *keV* x-ray photon is approximately 1,000 light photons (within a factor of 2)

The system allows replacement of the fluorescent screen, since the screen might be degraded over time. It also incorporates with the advancements in the area where more efficient screen might be available in the future.

CCD Module:

Sharp LZ2324J CCD photodetector array is used as an image sensor. It is 1/3 inch CCD with 542 Horizontal by 582 vertical pixel array. Each pixel has a dimension of 9.6 μm horizontal and 6.3 μm vertical. The lens used for each CCD has a f-number of 1.2. While back focal length is 8 *mm*, the image to screen distance is 4 inches.

The module consists of CCD driving circuitry, readout electronics and memory together with the CCD / lens pair. The charge information corresponding to the image formation in the sensor is clocked out by the vertical and horizontal timing signals. The charges accumulated in the photodetectors is shifted out serially as a voltage level. The method called "correlated double sampling", is used to obtain absolute pixel charge information from the CCD output signal. The method eliminates the dark noise created by electron hole recombination in the photodetectors and removes the feed-through signals from the analog output. The resulting signal is then amplified, and its level is adjusted to match the analog-to-digital converter. An 8-bit A/D is used for the conversion of analog pixel information to digital data. The A/D converter is chosen because of its low error level (+/- 1/2 low significant bit) and high speed. Detailed diagram of the acquisition circuit is given in the Appendix (CCD Module Schematic).

Each CCD module, additionally, contains memory (SRAM) unit as a frame buffer. The frame buffer is used to store each sub-image captured by its corresponding image sensor until it is read-out. In the device, there are total of 3 megabytes of storage area for single unprocessed image. The memory unit is controlled by the interface electronics located in the microcomputer.

Interface and Computer Unit:

The device is connected to a IBM-PC compatible 486DX2 microcomputer system for the reconstruction, processing and displaying images captured. The interface card provides necessary decoding schemes for the ISA bus architecture. It also contains timing circuitry to control the device and to generate the signals for the CCD modules. The circuit diagram of the interface circuitry is given in the Appendix (Timer / Interface Schematic). The system architecture allows the adaptation of the device for different bus architectures by modification of the interface board.

To achieve high speed image transfer, the data is transferred in parallel to the microcomputer's memory. One control register is provided in the interface card to allow individual access to selected CCD module. The detailed circuit diagrams can be found in the Appendix (Memory Schematic).

Earlier versions of the XRAYWIN program have employed the familiar Microsoft Windows graphical interface for user interaction. While this interface has proven popular for traditional computing tasks it is quite cumbersome for the device being designed. The current x-ray imager is equipped with a touch screen interface as the sole input device. Traditional menu system and scrolling bar interface is quite difficult to interact with due to the limited touch screen resolution in the neighborhood of the screen edges. Therefore a large control bar has been implemented for end-user interaction with the XRAYWIN software system. This control bar contains a series of on screen buttons which when pointed to by the user will implement a specific task. The buttons on the control bar are purposely designed so as to be large enough to easily 'depressed' accommodate the average user's finger size. Additionally, the entire control bar may be easily moved by the user to an arbitrary location on the screen so that no one portion of the capture image will be obscured from view.

4 Software and Image Reconstruction

A full featured image processing software system has been designed and implemented in support of the digital x-ray imager system. The software interface controls the imager hardware described in the previous section and performs image reconstruction and visualization tasks required by the system. After image reconstruction is completed, the final, high resolution image is displayed for the clinician. The implemented end-user interface provides a variety of image analysis and enhancement tools with which to enhance the visualization of the acquired digital radiograph.

A test screen based approach has been employed to rapidly determine regions of overlap, which can then be employed for image reconstruction. It is expected that such a test screen would be employed on a periodic basis to allow unit recalibration. The effectiveness of such a test screen approach has been demonstrated previously in earlier system prototypes. The current test screen approach has a significant speed advantage over many more complex registration approaches.

Image Reconstruction:

One of the simplest image registration techniques is based upon determining the correlation between a set of fiducial markers which can be localized in both imaged data sets. Such a technique has been described by Kessler, et. al. The ability to compute the best transform to map one sequence of points onto another was employed repeatedly in our reconstruction from tiled segments algorithm. This section presents the algorithm of least squared error mismatch employed to find the optimal transformation between sequences A and B .

In order to solve the point mapping problem, we wish to find the functional $F(>,|)$ which describes the spatial relationship between data ordered sequences $X_A(i,j)$ and $X_B(i,j)$. We make the approximation that the mismatch between sequences A and B be described completely by a combination of a fixed rotation, translation, and scaling which are valid over the whole area of each tile. Such a relationship can be expressed as the linear relationship;

$$\begin{aligned} x_A &= ax_B + by_B + c \\ y_A &= dx_B + ey_B + f \end{aligned} \quad (1)$$

or

$$\begin{aligned} x_B &= ax_A + by_A + c \\ y_B &= dx_A + ey_A + f \end{aligned} \quad (2)$$

where (x_A, y_A) and (x_B, y_B) represent coordinates in A and B , respectively.

The point mapping problem can now be solved by any process which can determine the parameters, a, b, c, d, e , and f , given two sets of points. A set of three points in each set is necessary to determine uniquely the parameters required in (2). However, it is common for both sets to contain greater than three corresponding points. Therefore, the system that must be solved for the desired parameters is overdetermined and an approximation technique is called for. A least-squares method can be employed to approximate the parameter set (a, b, c, d, e, f) given two sequences of corresponding points. The problem of solving for the parameter set can be divided into the two problems of finding the parameter set for equation (1) and then finding the parameters for equation (2). Only the solution for the solving for the parameters (a, b, c) of equation (1) will be presented in a detailed manner as the solution for equation (2) can be derived by using the discussion to follow and simple substitution of variables. The appropriate linear systems that can be solved for (a, b, c, d, e, f) given a set of matched fiducial points are presented in equations (12) and (12).

A generalized energy equation, J_x , may be defined as;

$$J_x = \sum_{i=1}^n (x_A^i - [ax_B^i + by_B^i + c])^2 \quad (3)$$

The energy function, J_x , must be minimized in terms of the desired parameter set (a, b, c) given a two sets A and B each containing n corresponding points in space.

$$(x_B^1, y_B^1 | x_A^1, y_A^1), \dots, (x_B^i, y_B^i | x_A^i, y_A^i), \dots, (x_B^n, y_B^n | x_A^n, y_A^n)$$

The values of a, b and c which minimize J may be determined by setting the partial derivative of J with respect of each of the parameters to zero and then solving the resultant system of equations for (a, b, c) . i.e.

$$\frac{\partial J_x}{\partial a} = -2 \sum_{i=1}^n x_B^i (x_A^i - [ax_B^i + by_B^i + c]) = 0 \quad (4)$$

$$\frac{\partial J_x}{\partial a} = -2 \sum_{i=1}^n x_B^i (x_A^i - [ax_B^i + by_B^i + c]) = 0 \quad (5)$$

$$\frac{\partial J_x}{\partial c} = -2 \sum_{i=1}^n (x_A^i - [ax_B^i + by_B^i + c]) = 0 \quad (6)$$

After some algebraic manipulations the above equations can be re-written as a system of three linear equations.

$$a \sum_{i=1}^n (x_B^i)^2 + b \sum_{i=1}^n x_B^i y_A^i + c \sum_{i=1}^n x_B^i = \sum_{i=1}^n x_B^i x_A^i \quad (7)$$

$$a \sum_{i=1}^n x_B^i y_B^i + b \sum_{i=1}^n (y_B^i)^2 + c \sum_{i=1}^n y_B^i = \sum_{i=1}^n y_B^i x_A^i \quad (8)$$

$$a \sum_{i=1}^n x_B^i + b \sum_{i=1}^n y_B^i + c \cdot n = \sum_{i=1}^n x_A^i \quad (9)$$

The desired parameter set (a, b, c) can then be determined by solving the two three dimensional linear systems of equations;

$$\begin{pmatrix} \sum_{i=1}^n (x_B^i)^2 & \sum_{i=1}^n x_B^i y_B^i & \sum_{i=1}^n x_B^i \\ \sum_{i=1}^n x_B^i y_B^i & \sum_{i=1}^n (y_B^i)^2 & \sum_{i=1}^n y_B^i \\ \sum_{i=1}^n x_B^i & \sum_{i=1}^n y_B^i & n \end{pmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^n x_B^i x_A^i \\ \sum_{i=1}^n y_B^i x_A^i \\ \sum_{i=1}^n x_A^i \end{bmatrix} \quad (10)$$

Subsequently, parameters (d, e, f) can be derived using A and B and the energy functional,

$$J_y = \sum_{i=1}^n (y_A^i - [dx_B^i + ey_B^i + f])^2 \quad (11)$$

J_y and an identical procedure to that presented above are used to arrive at the linear system of equations:

$$\begin{pmatrix} \sum_{i=1}^n (x_B^i)^2 & \sum_{i=1}^n x_B^i y_B^i & \sum_{i=1}^n x_B^i \\ \sum_{i=1}^n x_B^i y_B^i & \sum_{i=1}^n (y_B^i)^2 & \sum_{i=1}^n y_B^i \\ \sum_{i=1}^n x_B^i & \sum_{i=1}^n y_B^i & n \end{pmatrix} \begin{bmatrix} d \\ e \\ f \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^n x_B^i y_A^i \\ \sum_{i=1}^n y_B^i y_A^i \\ \sum_{i=1}^n y_A^i \end{bmatrix} \quad (12)$$

which can then be solved for the remaining parameters (d, e, f) .

Image Distortion:

Image distortion caused by non-ideal optical components is a common problem for many imaging systems. The small, portable nature of the desired end product requires a minimal screen to CCD distance. However, as this distance is reduced, barrel distortion is increased. High quality, custom lens components can be designed and manufactured so as to reduce or remove

this distortion. Custom lens design and production costs are far too prohibitive to justify their use on a pre-production prototype. Therefore, the barrel distortion must be corrected using software techniques. The software algorithm employed to correct the image distortion assumes that two sets of coordinate systems exist; coordinates (x,y) represent two-dimensional coordinates for the corrected image and coordinates (s,r) represent the original distorted image. If it is assumed that distortion can be modeled as a piecewise continuous set of small linear distortion functions, then the transform which maps distorted pixels to undistorted pixels can be written as the two equations:

$$s = ax + by + c \quad (13)$$

$$r = dx + ey + f \quad (14)$$

The above transform is then able to correct for rotational, translational and scaling distortion. In order to implement the distortion correction transform it is necessary to first determine the parameter set (a,b,c,d,e,f) for each region in which the transform will be applicable. A test screen which may be imaged by the hardware system is utilized to determine the parameters (a,b,c,d,e,f) . The test screen consists of a set of control points arranged in a square matrix array configuration. Every four points on the control screen define a square region which may be subdivided into two equivalent triangles by connecting either set of two non-adjacent square vertices. A distorted image of the original test screen may then be captured. Due to the fine matrix of control points, the non-linear barrel distortion may be modeled as linear within the finite region of each triangle. The parameter set (a,b,c,d,e,f) can be determined using the *a priori* knowledge of the control point locations coupled with the acquired image of the test screen. A series of six simultaneous equations is solved for each triangular region. This process is quite rapid and computation time is negligible for the current system configuration. After the parameter set (a,b,c,d,e,f) has been determined, it is possible to correct the acquired image's distortion through the use of the following algorithm.

Let $U(x,y)$ be a pixel value in the corrected image and $D(s,r)$ be a pixel in the distorted image. Then for each pixel value $U(x,y)$ in the "corrected" image,

1. Determine the triangular region, t which pixel (x,y) is a member of.
2. Retrieve the transform parameter set, $(a,b,c,d,e,f)_t$ for triangle t .
3. Calculate; $s=ax+by+c$ and $r=dx+ey+f$.
4. Let pixel $U(x,y) = D(s,r)$.

5 Results and Discussion

The imaging device's operation was tested completely with an optical source and a test screen. The device captures twelve (3 by 4) sub-images where each CCD sensor stores one related sub-image in its photodetector array as a charge accumulation. The charge is transferred out by a high speed electronics circuit which is partially controlled by a microcomputer. Images

are digitized and stored in the memory system as an image profile. The acquired data is then retrieved by the microcomputer unit for processing and display. Various image processing algorithms are available in the system for further evaluation of images. The image capture time is approximately 100 milliseconds. The retrieval and reconstruction of the complete image is completed in approximately 15 seconds.

Because there are overlaps between the subimages, the information at the edges of the sub-sections is not lost. The amount of the overlap on a test screen is used to calibrate and align the device. System calibration must be repeated periodically to correct for possible system deformation due to use or temperature change. The prototype of the device has isolated CCD modules mounted on a sturdy frame so that it is rigid enough to be used in the field. The modular configuration was selected because of its suitability for mechanical reconfiguration. After the radiographic image taken by the operator, the distortion due to the wide angle lenses is corrected. Then, full radiographic image is constructed by the removal of the overlaps. The system corrects the CCD's 3:2 aspect ratio to display unit aspect ratio of 1:1.

The images captured by the system are given in the following pages. The system is still being tested at the Erie County Medical Center, Buffalo, NY under the supervision of Dr. Stephen Rudin and Dr. Daniel Bednarek.

6 Conclusion

The digital x-ray imager is of particular value in areas of medical radiographic imaging where on line verification of the results are required. Furthermore, the system's compact design will allow the operator to use the imager in field hospitals or mobile medical units.

The device is capable of capturing high resolution images without information loss between the adjacent sensors. The system can accommodate all radiographic film sized as well as non-standard geometric configurations without loss of spatial resolution. It is expected that further development will yield a clinically viable digital x-ray acquisition system with wide spread applications for the radiology community.

The paper presented at the Physics of Medical Imaging Conference at SPIE Medical Imaging '96 is included in this report. The title of the paper is " Portable Digital Radiographic Imager: An overview" and summarizes the device developed in the study.

In the appendix, Figures 2 through 7, detailed circuits of the device are given. Figure 3 is the schematic of CCD modules; the following Figure 4 is a circuit diagram of the memory module; and the next ones are the connection board schematic, interface unit schematic and the buffer board circuit diagram.

Figures 8 through 12 are the radiographic images taken by the device. These images are not reconstructed, since we found difficulty localizing the overlap areas automatically. We use a wire mesh (Figure 10) to find the overlap regions so that the device can be calibrated to produce fully constructed radiographic images. However, since grids can not be distinguished from the neighbors, it is impossible to find the repeated ones in the overlap regions. If the construction is done manually, after several trials by the operator the grids can be distinguished and parameters which are needed for reconstruction are extracted. Localization information for each grid should be included in the test screen for automatic calibration. Currently, we are at the stage to implement a new test screen to overcome this problem.

Figure 13 is the display screen of the device. Basic image manipulation functions available to the operator through buttons which can be accessed by the touch screen interface. The touch screen is placed on the gray scale LCD display. The operator can also scroll around the image by using the buttons provided. In Figure 14, photographic pictures of the device are given. One includes the display and the image receptor, and the other one shows the CCD array which is located under the scintillation screen.

Refinement of the reconstruction software is still continuing while more tests are performed at Erie County Medical Center.

References

- [1] Cowen A.R., "Digital x-ray imaging," Measurement Science & Technology, 2:691-707, August 1991.
- [2] Gruner S.M. "CCD and vidicon x-ray detectors," Rev. of Scientific Instrumentation, 60(7), 1545-1551, July 1989.
- [3] M.L. Kessler, S. Pitluck, et. al. Integration of multimodality imaging data for radiotherapy treatment planning. International Journal of Radiation Oncology Biology Physics, 21:1653-1667, November 1991.
- [4] Karellas, A., Liu, H., Harris, L., D'Orsi, C., "Operational characteristics of scientific grade charge coupled devices in x-ray imaging applications," SPIE Vol 1655, 85-91 (1992).
- [5] Karellas, A. Harris, L.J., Davis, M.A., "Design and evaluation of a prototype CCD-based imaging system for electronic radiography," Med. Phys, (Abstr) 16, 681 (1989).
- [6] Roehrig, H., Ovitt, T.W. Dallas, W.J., R.D., Vercillo, R., McNeill, K.M. "Development of a high resolution x-ray imaging device for use in coronary angiography," SPIE Proc. 767, 144-153 (1987).
- [7] Cowen A.R. "Digital x-ray imaging," Measurement Science & Technology, 2:691-707, Aug'1991.
- [8] Zweig, G., and Zweig, D., " Radioluminescent Imaging: factors affecting total light output," SPIE Proc. 419, 297-304 (1983).

APPENDIX

IMAGING DEVICE

CCD MODULE SCHEMATIC (PCB #1)

MEMORY SCHEMATIC (PCB #2)

CONNECTION BOARD (PCB #3)

TIMER/INTERFACE SCHEMATIC (PCB #4)

COMPUTER CONNECTION BOARD (PCB #5)

HAND PHANTOM (3x4 CCD ARRAY)

HAND PHANTOM (3x4 CCD ARRAY) INVERTED

HAND PHANTOM (3x4 CCD ARRAY) WITH WIRE MESH

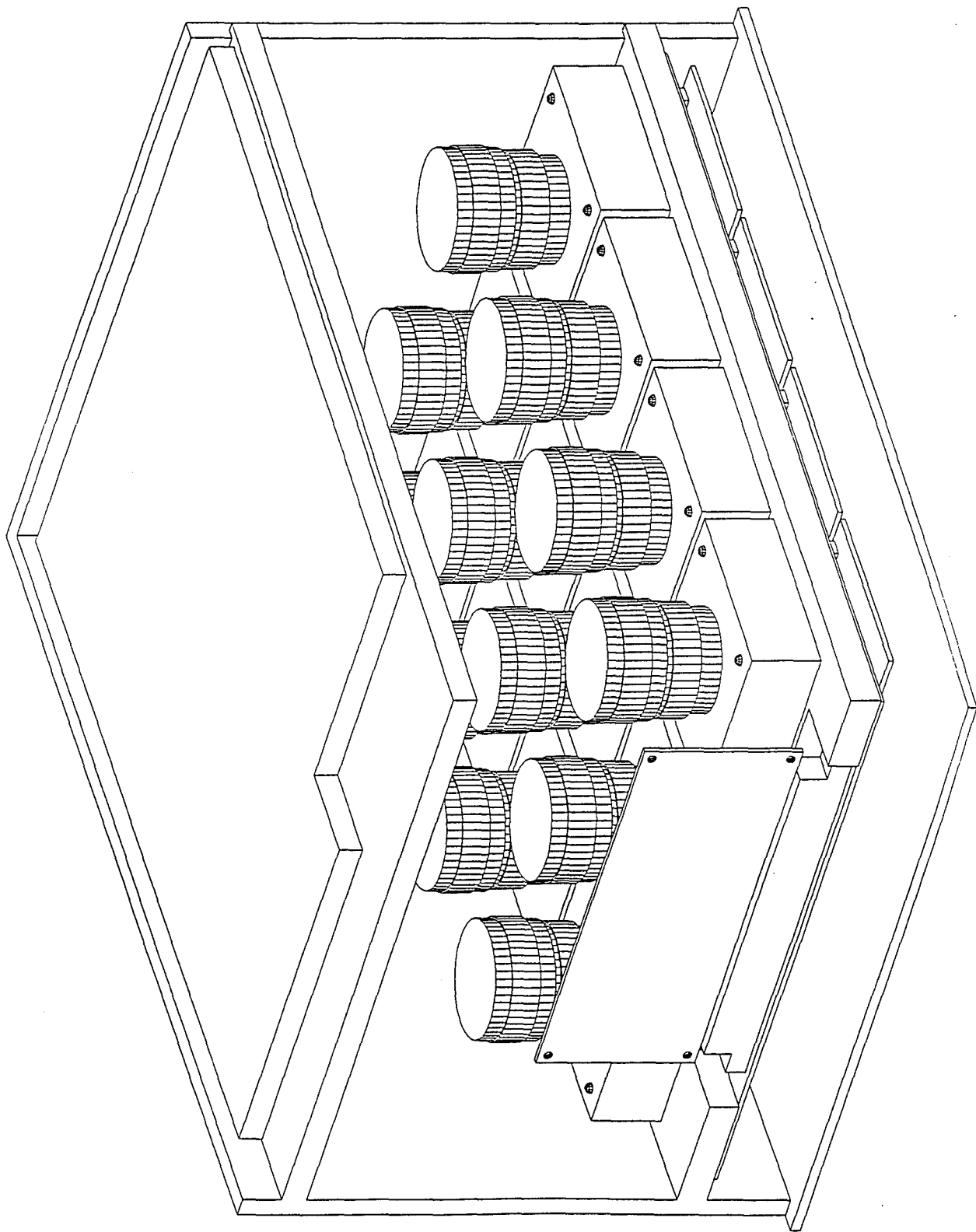
KNEE PHANTOM (3x4 CCD ARRAY)

KNEE PHANTOM (3x4 CCD ARRAY) INVERTED

DISPLAY OF THE DEVICE

COMPACT DIGITAL X-RAY IMAGING DEVICE

ABSTRACT



Imaging Device
Figure 2

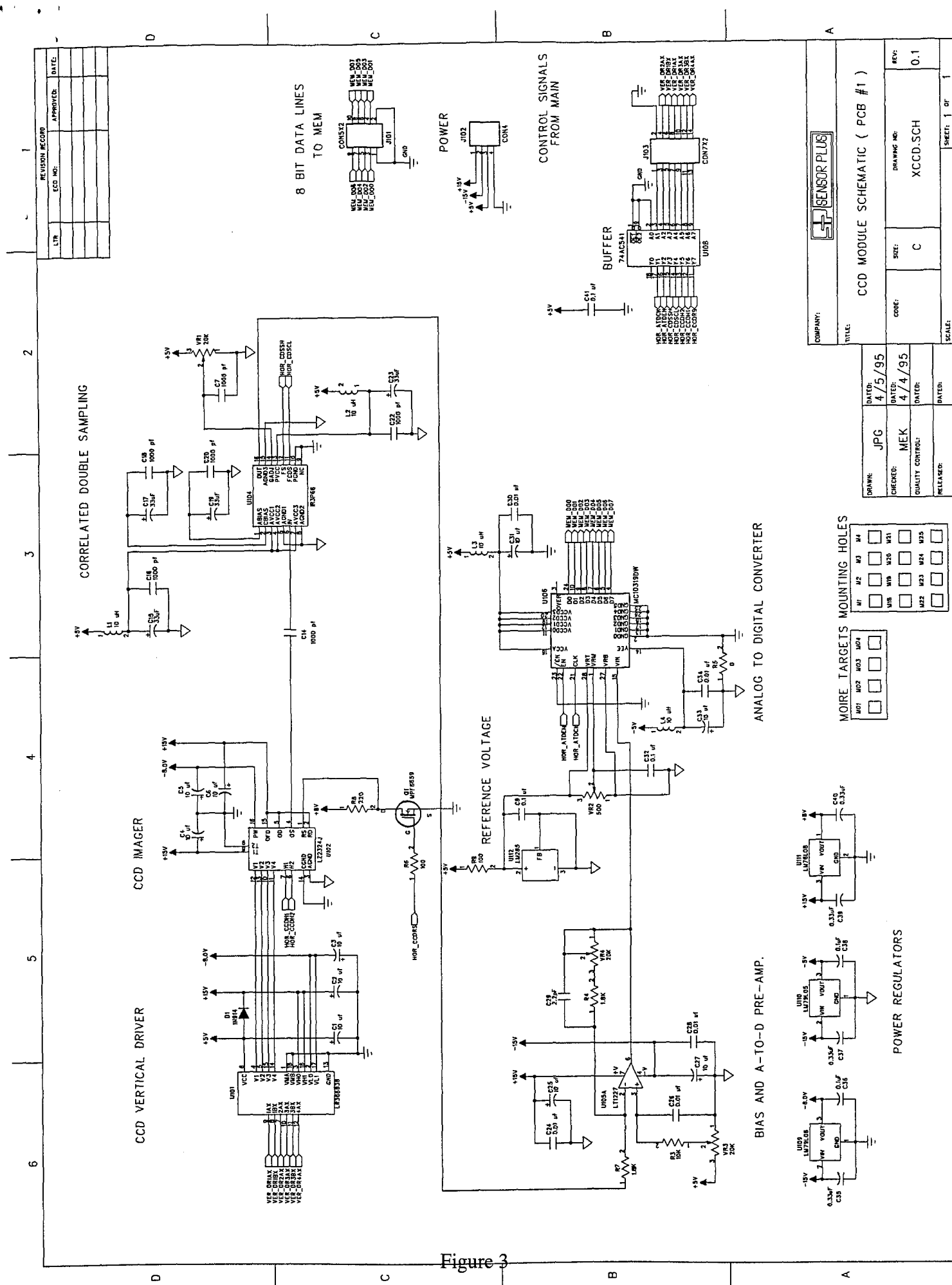


Figure 3

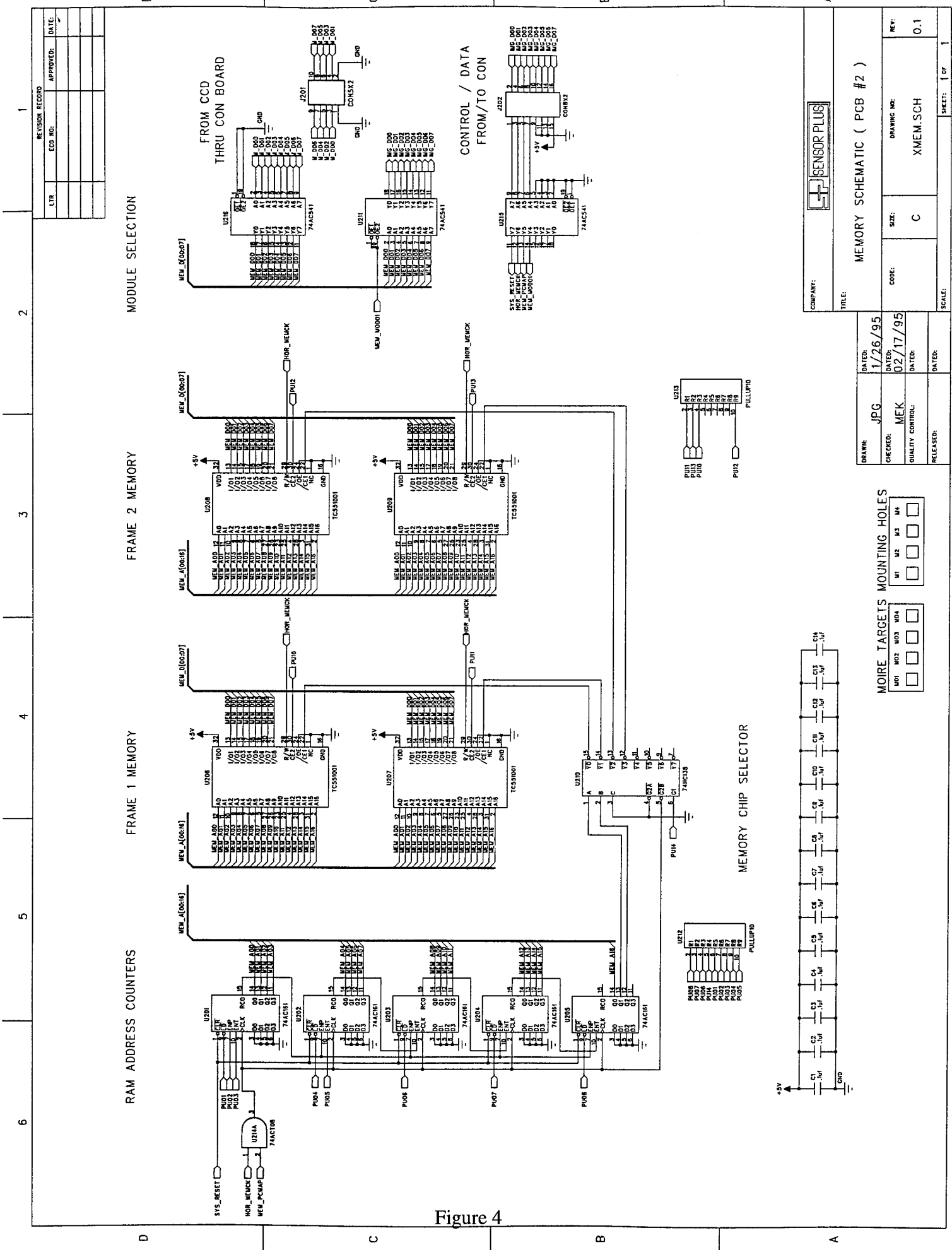


Figure 4

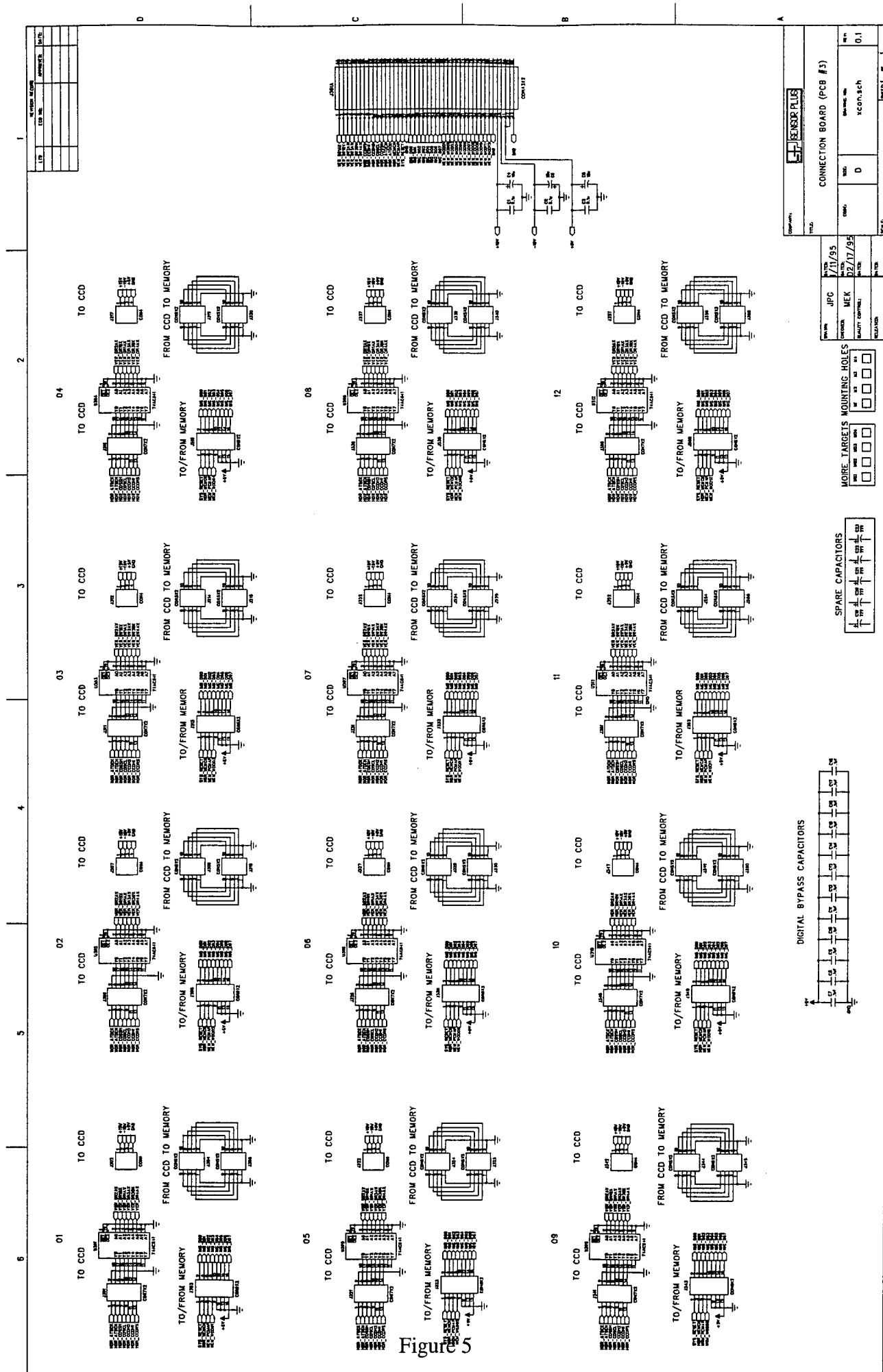


Figure 5

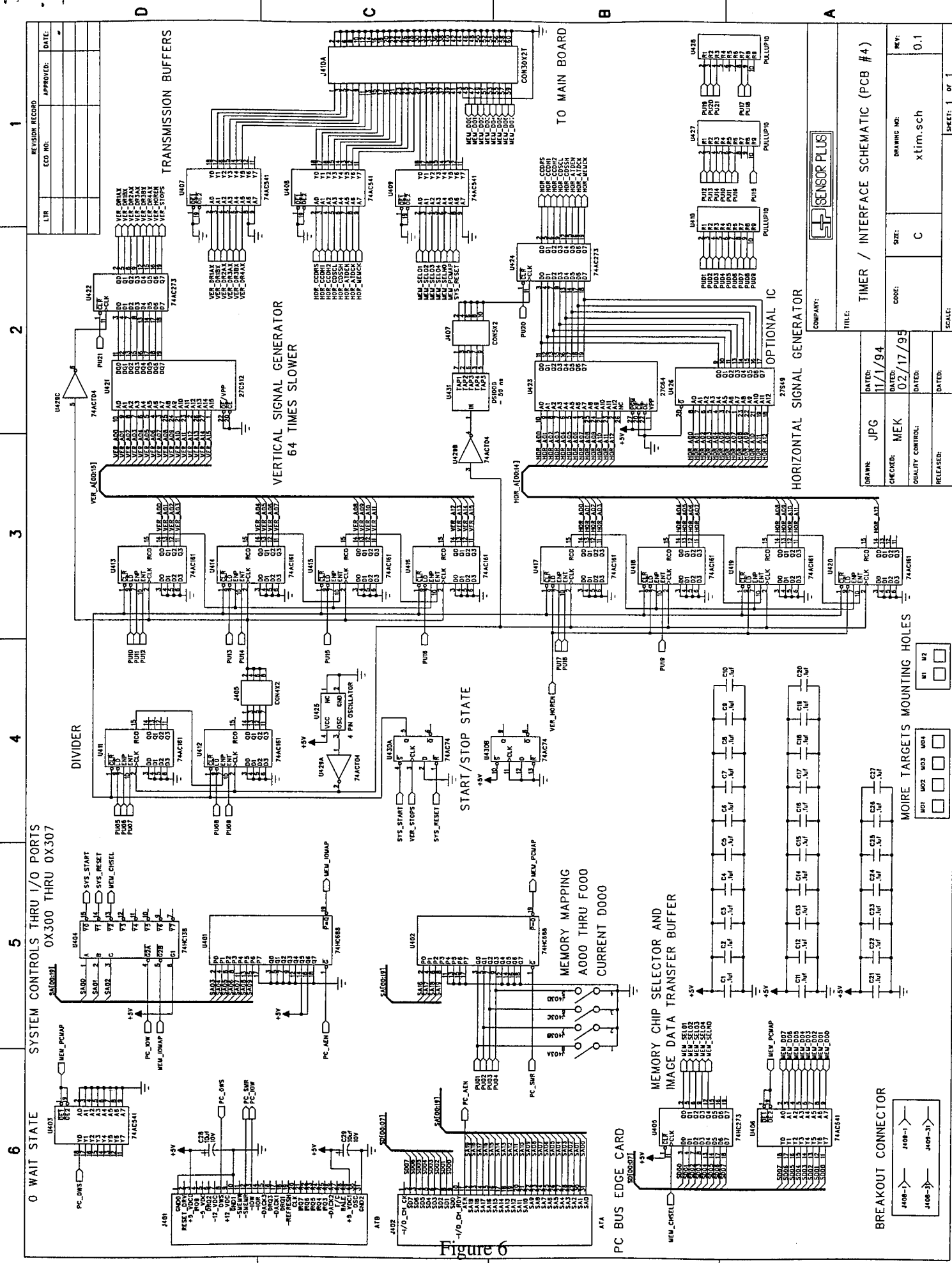


Figure 6



Figure 8 Hand Phantom (3x4 CCD array)



Figure 9 Hand Phantom (3x4 CCD array) inverted

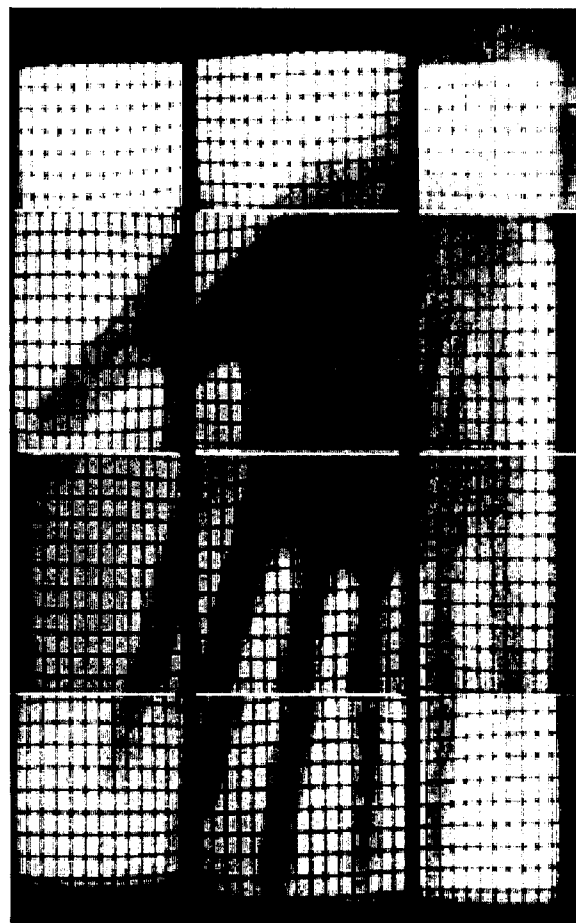


Figure 10 Hand Phantom (3x4 CCD array) with wire mesh

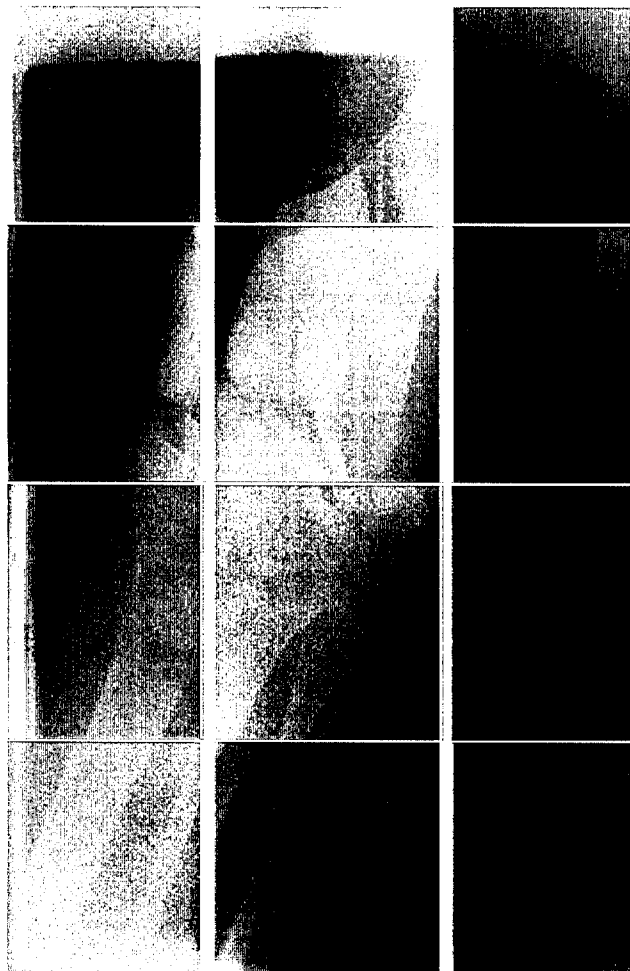


Figure 11 Knee Phantom (3x4 CCD array)



Figure 12 Knee Phantom (3x4 CCD array) inverted

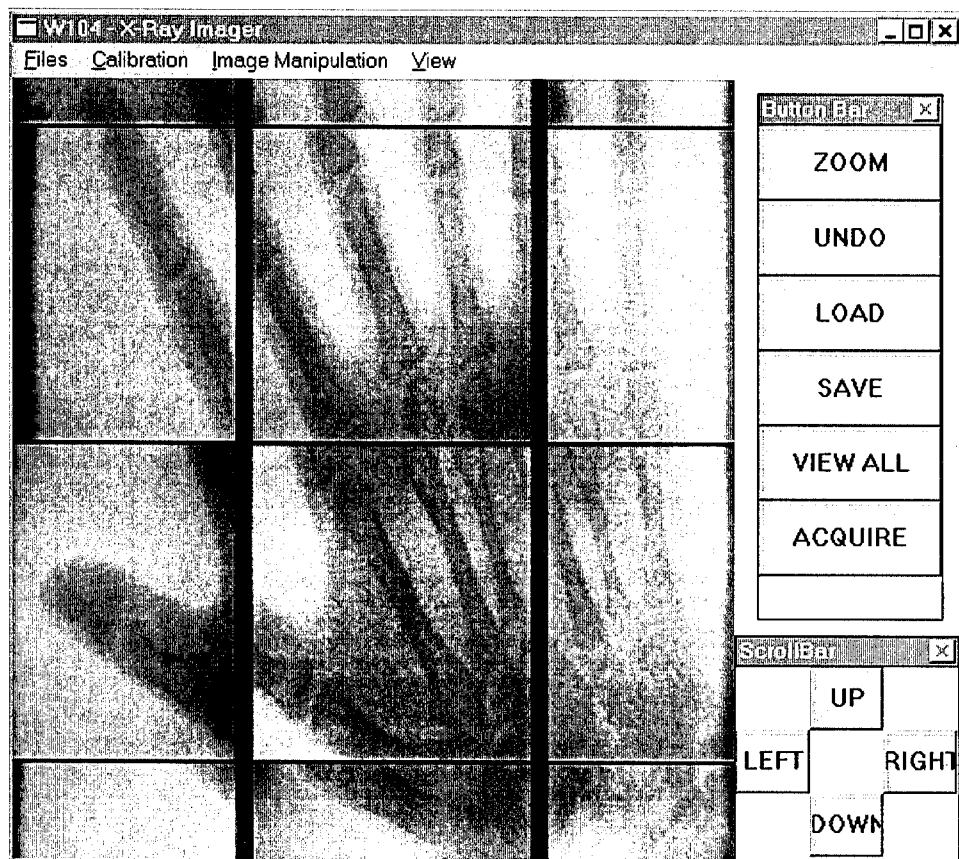


Figure 13 Display of the device

Digital Radiographic Imager

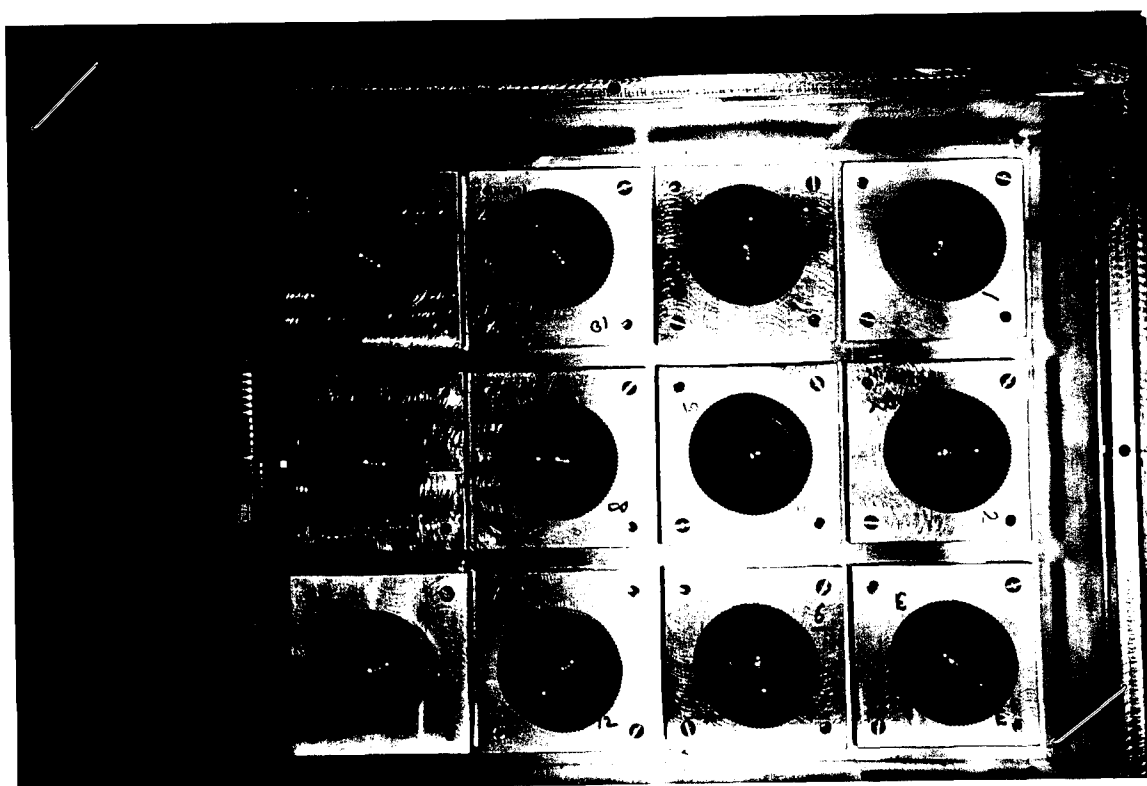
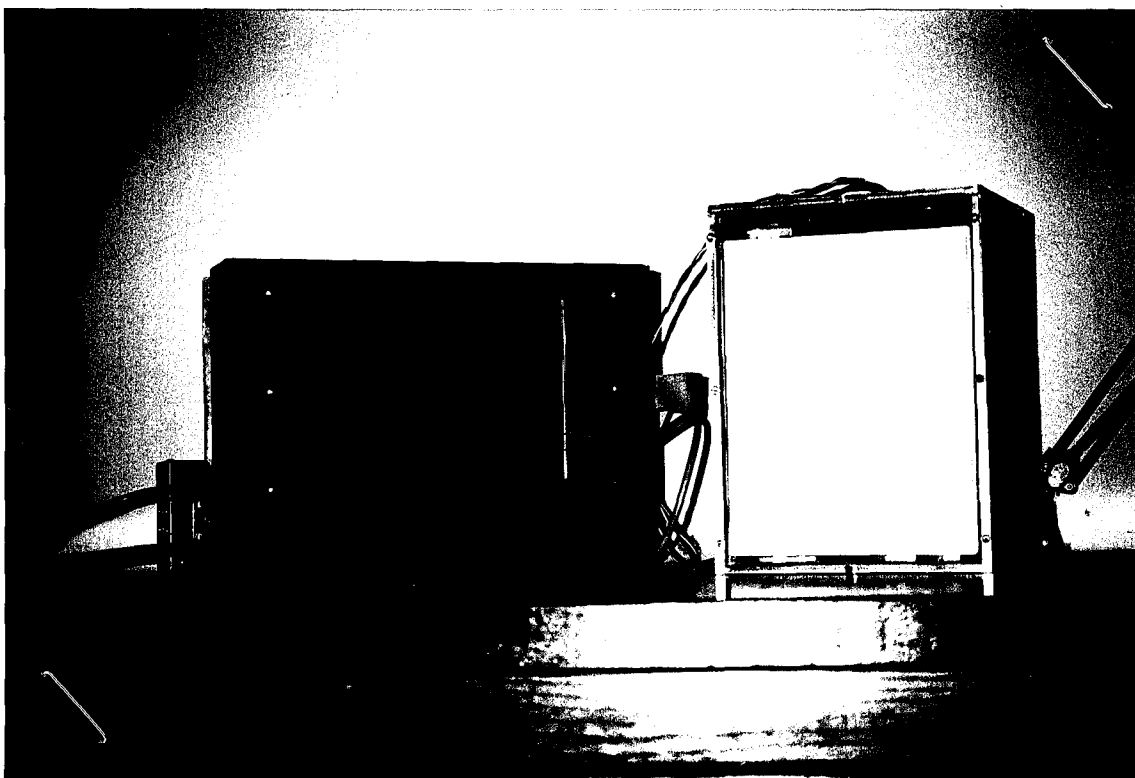


Figure 14

Portable Digital Radiographic Imager: An Overview*

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January 10, 1996

ABSTRACT

Pre-production prototype of a low-cost, portable, compact digital radiographic imaging device which replaces current film based systems has been constructed and tested. Currently, it is in the process of full utilization for field hospitals where immediate verification of the results is essential. For the particular pre-production unit, image acquisition is performed by a 3x4 matrix of charge-coupled-device (CCD) imaging sensors which view the output of a standard x-ray scintillation screen via an off-the-shelf optical system. The use of multiple, moderately priced CCD sensors results in a high resolution system with a low cost of production relative to other digital imaging systems of comparable resolution. The field of view each CCD are purposefully overlapped so as to facilitate image reconstruction. The acquisition of each radiographic image formed on a scintillation screen results in the production of twelve sub-images. A software algorithm is employed to detect the regions of overlap and a create a single continuous digital radiograph from the raw CCD data. Software methods are utilized to correct for barrel distortion affects that are caused by the use of low cost lens components.

Keywords: digital radiography, image processing, charge-coupled-devices, scintillation screens, fluoroscopy

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1 INTRODUCTION

Radiographic film is the most common conventional detector in which scintillation screen, together with a photographic film, is used. The scintillation screen is used to convert x-ray photons to visible light photons. The film is exposed during the radiation by the illumination of the fluorescent screen. Then it is chemically processed to obtain the resulting radiographic image. In this study, cost effective radiographic image reception device has been developed and fabricated to overcome the limitations of radiographic film and its processing. The new imaging device is intended to be used where film processing equipment or facilities can not be placed, and where on-line verification of the results is needed during the treatment; such as field hospitals or mobile medical units.

Pre-production prototype of a low-cost, portable, compact digital radiographic imaging device which replaces current film based systems has been constructed and tested. Currently it is in the process of full utilization for field hospitals where immediate verification of the results is essential. For the particular pre-production unit, image acquisition is performed by a 3x4 matrix of charge-coupled-device (CCD) imaging sensors which view the output of a standard x-ray scintillation screen via an off-the-shelf optical system. The use of multiple, moderately priced CCD sensors results in a high resolution system with a low cost of production relative to other digital imaging systems of comparable resolution. The field of view each CCD are purposefully overlapped so as to facilitate image reconstruction. The acquisition of each radiographic image formed on a scintillation screen results in the production of twelve sub-images. A software algorithm is employed to detect the regions of overlap and create a single continuous digital radiograph from the raw CCD data.

The software interface controls the imager hardware and performs image reconstruction and visualization tasks required by the system. Image reconstruction software consists of an algorithm to correct for barrel distortion effects that are caused by the use of low cost lens components, and sub image alignment algorithm to create single, continuous radiographic image. The image capture time is approximately 100 *milliseconds*. Retrieval and reconstruction of the complete image is performed in approximately 15 *seconds*. For the pre-production unit, screen to Imager distance has been reduced down to 3 inches which further decreases the total imaging device thickness to 6 inches (overall Imager dimensions are now 8.5"W x 10.5"L x 6"H for 8" x 10" view.) The radiographic images captured have 3 *lines/mm* resolution over the 8" x 10" field of view.

The digital radiographic imager is of particular value in areas of medical radiographic imaging where on-line verification of the results are required. Furthermore, the systems portability will allow the operator to use the imager in field hospitals or mobile medical units. Also modularity of the CCD matrix layout allows the systems to be reconfigured for different size imaging areas without any reduction of the spatial resolution per unit.

2 REQUIREMENTS

The development goals for the compact x-ray imager system were as follows;

- Acquire a digitized image for further image manipulation and processing,
- Present the images immediately to the operator during treatment,
- Maintain compatibility with conventional radiographic film sizes,
- Provide high degree system portability for use in field hospitals,
- Have dynamic range and spatial resolution comparable to conventional systems,

- With relative low cost,
- Furnish open/expendable architecture (change of detector area).

3 ARCHITECTURE

Image acquisition is performed by a 3x4 matrix of charge-coupled-device (CCD) imaging sensors which view the output of a standard x-ray scintillation screen via an optical system. The use of multiple, moderately priced CCD units results in a high resolution system with a low cost of production relative to other digital imaging systems of comparable resolution. The acquisition of each radiographic image formed on a scintillation screen results in the production of twelve sub-images. A software algorithm is employed to detect the regions of overlap and create a single, continuous digital radiograph from the raw CCD data. Software methods are utilized to correct for barrel distortion affects that are caused by the low cost lens components.

The system has been designed to include following sections; A fluorescent screen to convert x-rays to visible light, Multiple image-sensor/lens pairs each capturing one segment of the image on the fluorescent/optical screen, Data acquisition system to condition CCD's analog signal output and to obtain digital pixel information, Memory/interface unit to store the acquired data and to transfer the data to a computer system for further processing, Portable computer system with display, A touch screen for the system/operator interaction, Alignment grid for the calibration of the detector, Reconstruction software for the alignment of the individual segments, and Image processing software for further refinement of the images by an operator.

Radiographic images on the order of 3 *lines/mm* (or 768x1024 pixels) are acquired rapidly over a 8"x10" field of view. A matrix configuration of twelve CCD area imagers are utilized in parallel so as to reduce screen to imager distance and acquisition time significantly. Modularity of the CCD matrix layout allows the system to be reconfigured for different imaging areas without any reduction of the spatial resolution per unit. Successful operation has been verified using screen to imager distance of 4 inches with off-the-shelf optics. Further distance reductions are possible with custom optical configurations. The captured radiographic images are displayed instantly on an CRT and/or LCD depend upon the computer system configuration.

4 SOFTWARE and IMAGE RECONSTRUCTION

A full featured image processing software has been designed and implemented in support of the digital x-ray imager. The software interface controls the imager hardware, and performs image reconstruction and visualization tasks required. After image reconstruction is completed, the final, high resolution image is displayed for the operator. End user interface provides variety image enhancement and image analysis tools.

A test screen based approach has been employed to rapidly determine regions of overlap which can than be used for image reconstruction. It is expected that such a test screen would be needed on a periodic bases to allow unit calibration. The effectiveness of such a test screen approach has been demonstrated in earlier system prototypes. The current test screen approach has a significant speed advantage over many more complex registration approaches.

Image Reconstruction :

One of the simple image registration techniques is based upon determining correlation between a set of fiducial markers which can be localized in both imaged data sets. Such a technique has been described by Kessler et. al.. The ability to compute the best transform to map one sequence of points onto another was employed

repeatedly in our reconstruction from tiled segments algorithm. This section presents the algorithm of least squared error mismatch employed to find the optimal transformation between sequences A and B .

In order to solve the point mapping problem, we wish to find the functional $F(>,|)$ which describes the spatial relationship between data ordered sequences $X_A(i,j)$ and $X_B(i,j)$. We make the approximation that the mismatch between sequences A and B can be described completely by a combination of a fixed rotation, translation, and scaling which are valid over the area of each tile. Such a relationship can be expressed as the linear relationship;

$$\begin{aligned} x_A &= ax_B + by_B + c \\ y_A &= dx_B + ey_B + f \end{aligned} \quad (1)$$

or

$$\begin{aligned} x_B &= ax_A + by_A + c \\ y_B &= dx_A + ey_A + f \end{aligned} \quad (2)$$

where (x_A, y_A) and (x_B, y_B) represent coordinates in A and B , respectively.

The point mapping problem can now be solved by any process which can determine the parameters a, b, c, d, e , and f given two sets of points. A set of three points in each set is necessary to determine uniquely the parameters required in (2). However, it is common for both sets to contain greater than three corresponding points. Therefore, the system that must be solved for the desired parameters is over-determined and an approximation technique is called for. A least square method can be employed to approximate the parameter set (a, b, c, d, e, f) given two sequences of corresponding points. The problem of solving for the parameter set can be divided into two problems of finding the parameter set for the equation (1) and then finding the parameters for equation (2). Only the solution for the solving for the parameters (a, b, c) of the equation (1) will be presented in a detailed manner. As the solution for the equation (2) can be derived by using the discussion to follow and simple substitution of variables. The appropriate linear systems that can be solved for (a, b, c, d, e, f) given set of matched fiducial points are presented in (8).

A generalized energy equation, J_x , may be defined as;

$$J_x = \sum_{i=1}^n (x_A^i - [ax_B^i + by_B^i + c])^2 \quad (3)$$

The energy function, J_x , must be minimized in terms of the desired parameter set (a, b, c) given a two sets A and B each containing n corresponding points in space.

$$(x_B^1, y_B^1 | x_A^1, y_A^1), \dots, (x_B^i, y_B^i | x_A^i, y_A^i), \dots, (x_B^n, y_B^n | x_A^n, y_A^n)$$

The values of a, b , and c which minimize J may be determined by setting the partial derivative of J with respect of each of the parameters to zero and then solving the resultant systems of equations for (a, b, c) . i.e.

$$\begin{aligned} \frac{\partial J_x}{\partial a} &= -2 \sum_{i=1}^n x_B^i (x_A^i - [ax_B^i + by_B^i + c]) = 0 \\ \frac{\partial J_x}{\partial b} &= -2 \sum_{i=1}^n y_B^i (x_A^i - [ax_B^i + by_B^i + c]) = 0 \\ \frac{\partial J_x}{\partial c} &= -2 \sum_{i=1}^n (x_A^i - [ax_B^i + by_B^i + c]) = 0 \end{aligned} \quad (4)$$

After some algebraic manipulations above equations can be rewritten as a systems of three linear equations.

$$\begin{aligned}
 a \sum_{i=1}^n (x_B^i)^2 + b \sum_{i=1}^n x_B^i y_A^i + c \sum_{i=1}^n x_B^i &= \sum_{i=1}^n x_B^i x_A^i \\
 a \sum_{i=1}^n x_B^i y_B^i + b \sum_{i=1}^n (y_B^i)^2 + c \sum_{i=1}^n y_B^i &= \sum_{i=1}^n y_B^i x_A^i \\
 a \sum_{i=1}^n x_B^i + b \sum_{i=1}^n y_B^i + c \cdot n &= \sum_{i=1}^n x_A^i
 \end{aligned} \tag{5}$$

The desired parameter set (a, b, c) can then be determined by solving the two three dimensional linear systems of equations;

$$\begin{bmatrix} \sum_{i=1}^n (x_B^i)^2 & \sum_{i=1}^n x_B^i y_B^i & \sum_{i=1}^n x_B^i \\ \sum_{i=1}^n x_B^i y_B^i & \sum_{i=1}^n (y_B^i)^2 & \sum_{i=1}^n y_B^i \\ \sum_{i=1}^n x_B^i & \sum_{i=1}^n y_B^i & n \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^n x_B^i x_A^i \\ \sum_{i=1}^n y_B^i x_A^i \\ \sum_{i=1}^n x_A^i \end{bmatrix} \tag{6}$$

Subsequently, parameters (d, e, f) can be derived using A and B and the energy functional,

$$J_y = \sum_{i=1}^n (y_A^i - [dx_B^i + ey_B^i + f])^2 \tag{7}$$

J_y and an identical procedure to that presented above are used to arrive at the linear system of equations;

$$\begin{bmatrix} \sum_{i=1}^n (x_B^i)^2 & \sum_{i=1}^n x_B^i y_B^i & \sum_{i=1}^n x_B^i \\ \sum_{i=1}^n x_B^i y_B^i & \sum_{i=1}^n (y_B^i)^2 & \sum_{i=1}^n y_B^i \\ \sum_{i=1}^n x_B^i & \sum_{i=1}^n y_B^i & n \end{bmatrix} \begin{bmatrix} d \\ e \\ f \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^n x_B^i y_A^i \\ \sum_{i=1}^n y_B^i y_A^i \\ \sum_{i=1}^n y_A^i \end{bmatrix} \tag{8}$$

which can then be solved for the remaining parameters (d, e, f) .

5 CONCLUSION

The digital x-ray imager of particular value in areas of medical radiographic imaging where on-line verification of results are required. Furthermore, the system's compact design will allow the operator to use the imager in field hospitals or mobile medical units.

The device is capable of capturing high resolution images without information loss between adjacent sensors. The system can accommodate all radiographic film sizes as well as non standard geometrical configuration without loss of spatial resolution. It is expected that further development will yield a clinically viable digital x-ray acquisition system widespread applications for the radiology community.

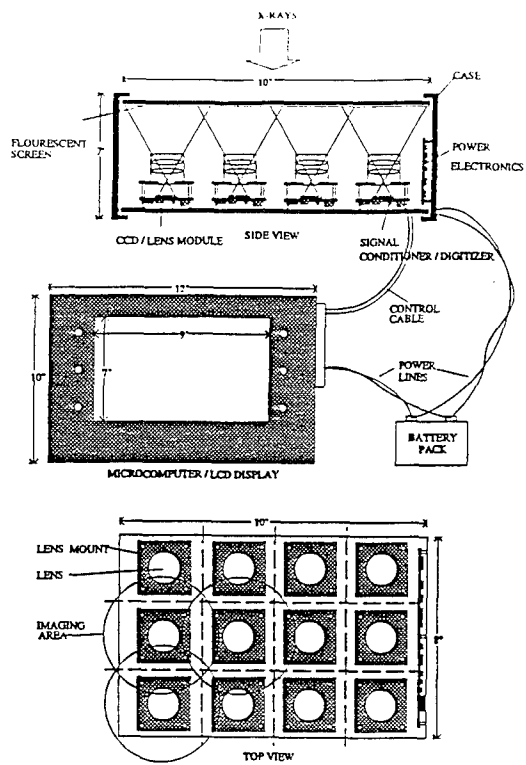


Figure 1

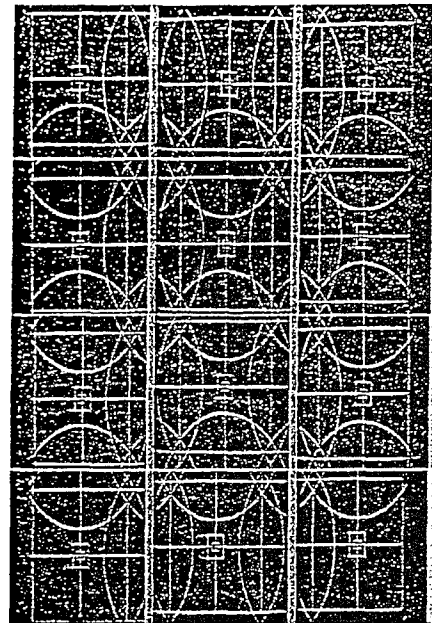


Figure 2

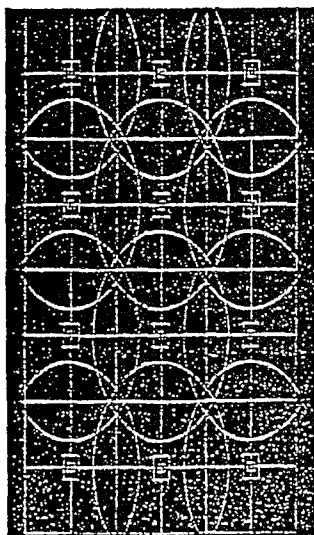


Figure 3

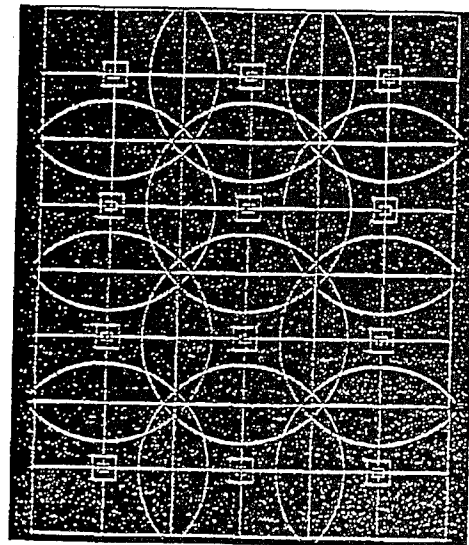


Figure 4

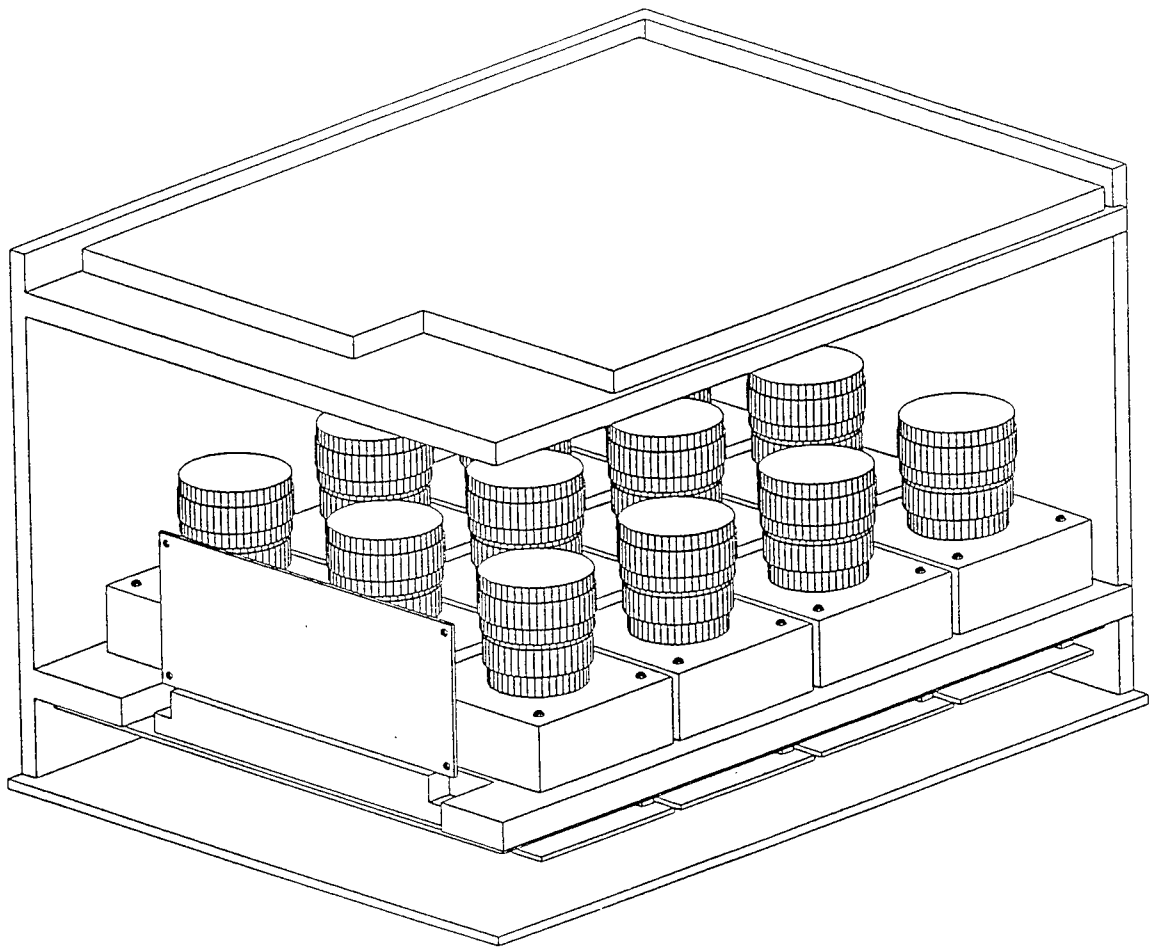


Figure 5

6 REFERENCES

- [1] Cowen, A. R., " Digital X-Ray Imaging, " *Measurement Science and Technology*, 2:691-707, August 1991.
- [2] Gruner, S. M., "CCD and vidicon x-ray detectors, " *Rev. of Scientific Instrumentation*, 60(7), 1545-1551, July 1989.
- [3] Karellas, A., Liu, H., Harris, L., D'Orsi, C., "Operational characteristics of scientific grade charge coupled devices in x-ray imaging applications," *SPIE Vol.1655*, 85-91, 1992.
- [4] Karellas, A., Harris, L. J., Davis, M. A., "Design and evaluation a prototype CCD-based imaging system for electronic radiography," *Med. Phys.* (Abstr.) 16, 681, 1989.
- [5] Kessler, M. L., Pitluck, S., et. al. "Integration of multimodality imaging data for radiotherapy treatment planning," *International Journal of Radiation Oncology Biology Physics*, 21: 1653-1667, November 1991.
- [6] Liu, H., Karellas, A., Harris, L.J., and D'Orsi, C., "Methods to calculate the lens efficiency in optically coupled CCD x-ray imaging systems," *Med. Phys.*, 21(7), 1193-1195, 1994.
- [7] Roehrig, H., et.al. "Development of high resolution x-ray imaging device for use in coronary angiography," *SPIE Proc.* 767, 144-153, 1987.
- [8] Zweig, G., and Zweig, D., " Radioluminant imaging: Factors affecting total light output," *SPIE Proc.* 419, 297-304, 1983.

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